International Journal of Mechanical and Production
Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 5, Issue 6, Dec 2015, 1-8

SIMULATION OF PARTICLE & LIQIUD IMPACT ON WATER FILM UNDER EQUIDENSE CONDITIONS USING SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

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ABSTRACT

In today's era of research, a constant need of simulating real time physical problems has been sensed. This gives researchers an

Edge of predicting experimental results on software packages without actually conducting expensive, time consuming experiments. But, for efficiency and accuracy in results, care must be taken in building up the base models for these softwares, developing concepts and algorithms which consider maximum physical real time parameters for the computations. Researchers have classified physical fields into various sections and have developed techniques for their fine simulation. One such technique, used for simulating continuous flow is Smoothed Particle Hydrodynamics (SPH). The paper deals with the simulation of a few real time continuous flow situations using SPH as a computational tool. SPH is a flexible method for hydrodynamics, extensively being used for simulation of continuous fluidic flow. A nice aspect of SPH is that it is Lagrangian. Another nice aspect of the method is that it has no numerical bulk viscosity. In all, the method is very useful for many problems of hydrodynamics, as long as inaccuracies and potential problems are kept in mind.

KEYWORDS: Smoothed Particle Hydrodynamics (SPH), YADE, Density Function

Received: Nov 07, 2015; **Accepted:** Nov 20, 2015; **Published:** Nov 21, 2015; **Paper Id.:** IJMPERDDEC20151

Original Article

INTRODUCTION

Smoothed particle hydrodynamics (SPH) was invented to simulate non-axisymmetric phenomena in astrophysics (Lucy 1977, Gingold& Monaghan 1977). The SPH method is a particle method. Unlike the particle in cell method (PIC) (Harlow 1957, 1974, 1988), SPH does not need a grid to calculate spatial derivatives. Instead, they are found by analytical differentiation of interpolation formulae. The equations of momentum and energy become sets of ordinary differential equations which are easy to understand in mechanical and thermodynamic terms. For example, the pressure gradient becomes a force between pairs of particles. The astrophysicist can then use intuition in a way which is difficult with the original partial differential equations. This intuition, coupled with detailed analysis, has allowed SPH to be extended to a wide variety of astrophysical problems. Although very accurate finite difference methods exist and these are better than SPH for some problems, they cannot handle complex physics in three dimensions with the same ease. The method, basically developed to study gas dynamics in astrophysical systems, is equally applicable in 1, 2 and 3 space dimensions.[1]

COMPUTATIONAL STRUCTURE

In SPH, a physical value at position *x*is calculated as a weighted sum of physical values *φj*of neighboring particles *j*

$$\varphi(\boldsymbol{x}) = \sum_j^n mj\varphi j/\rho jW(\boldsymbol{x} - \boldsymbol{x}j)$$

where*mj*, *ρj*, ***xj***are the mass, density and position of particle j, respectively and W is a weight function.

The density of fluid is calculated as-

$$\rho(\boldsymbol{x}) = \sum_j^n mjW(x - xj)$$

To compute the density of each particle, above equation has to be calculated. The indices of neighboring particles of particle *i* can be found with generated bucket texture. Using the index of particle, position can be read from position texture. Then the density of particle *i* is calculated by weighted sum of mass of neighboring particles, which is then written in density texture. If the particle is within effective radius to wall boundary, contribution of wall to density has to be estimated in two steps. In the first step, distance from particle *i* to wall is looked up from the distance function stored in a three-dimensional texture. Then the wall weight function stored in one dimensional texture is read with a texture coordinate calculated by distance to the wall. The contribution of wall boundary to density is added to density calculated among particles. Similarly, to compute the pressure and viscosity forces, neighboring particles have to be searched for again. The pressure force **F** press and the viscosity force **F**v is are computed as

$$\boldsymbol{F}pressi = -\sum_j^n mj[\frac{pi+pj}{2\rho j}]\nabla Wpress(\boldsymbol{r}ij)$$

$$\boldsymbol{F}visi = v\sum_j^n mj[\frac{vj-vi}{\rho j}]\nabla Wvis(\boldsymbol{r}ij)$$

Where ***r****ij* is the relative position vector and is calculated as ***r****ij*= ***r****j* –***r****i*; ***r****i*, ***r****j*are positions of particles *i*and *j*, respectively. The pressure force from wall boundary is computed using distance function. Then, updated velocity is written in another velocity texture. Using the updated velocity texture, the position is calculated with an explicit Euler integration,

$$x'i = xi + vidt$$

Where *x i* and *vi* are previous position and velocity of particle *i*, respectively. The updated position *x'i*is written to another position texture.[2]

A few applications of SPH include

- Binary Stars, Supernovae and Stellar Collisions
- Cosmological, Galactic Problems, Fragmentation and Cloud Collisions
- Motion Near Black Holes
- Magnetic Phenomena
- Special and General Relativity [3]

Table 1: Advantages and Disadvantages of SPH

Advantage	Disadvantage
No geometry constraints	Shocks broadened
Auto resolution	Mixing
Perfect advection	Conduction by hand
Energy conservation	Visualization
Easy n-Body coupling	Derivative estimator

SIMULATION REVIEW

Smoothed particle hydrodynamics (SPH) is a particle-based method for simulating the behavior of fluids. Each computational particle carries along information about the fluid in a little region, such as velocity and density; and during the course of simulation, these particles interact with each other in a way that models the dynamics of a fluid. Here, a simple 2D version of SPH method has been tuned. Afew real time liquid flow problems have been analyzed and simulated in using SPH in an open source YADE platform. An extensive simulation of the following cases was made –

- Simulation of particle impact on a liquid film when the densities of particle and liquid film are same.
- Simulation of liquid droplet impact on a liquid film when densities of droplet and liquid film are same.

SIMULATION OF PARTICLE IMPACT ON A LIQUID FILM WHEN DENSITIES OF PARTICLE AND LIQUID FILM ARE SAME

In the given simulation below, an impact of granular sized particle on liquid (water) film has been studied when thickness of film is almost same as diameter of falling body andthe densities of the falling body and film are same.

Parameters

SPH-Parameters

- Density, rho=1000.0 Kg
- Viscosity, mu=1 centipoise
- numerical speed of sound squared, k=1000
- 2D mass correction(ortho packaging), gamma=2.855
- Gravity acceleration, g= 9.81 m/s2
- time step, O.dt = 0.0001s

Geometry Parameters

- geometry width, X =.99
- geometry height, Y =.066
- number of spheres in z-direction, sphereNumDepth = 1
- number of spheres in y-direction, sphereNumHeight = 19.2
- number of wall layers,sphereNumWall = 2

- sphere radius,Rad = 0.5*Y/sphereNumHeight
- number of spheres in x-direction, sphereNumWidth = 0.5*X/Rad
- fallingHeight = 0.5*sphereNumHeight/Y
- fallingHeight = discDiam/0.11*0.5/Rad
- number of particles above fluid surface, overHeight = 0.15*sphereNumHeight
- smoothing length, h = 4*Rad [4]

RESULTS

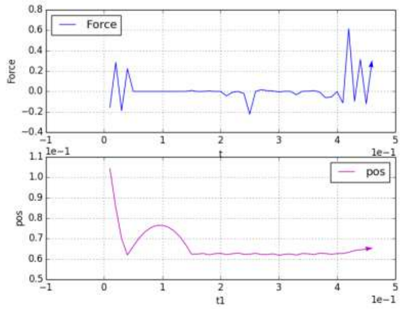


Figure 1: Position & Force Variation of One of the Falling Body with Time

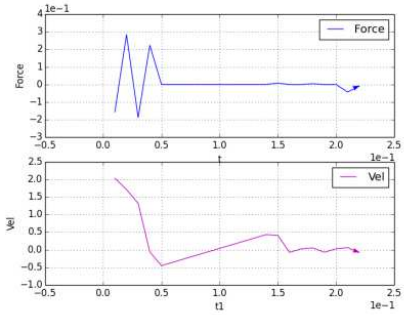
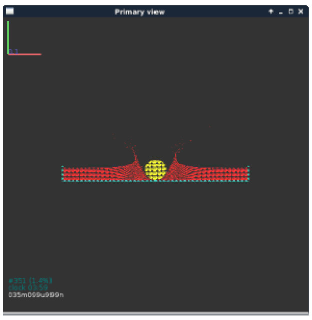
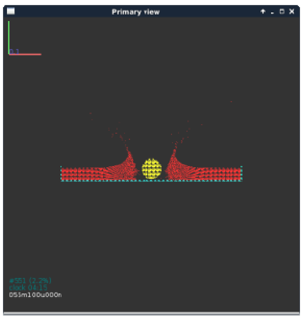
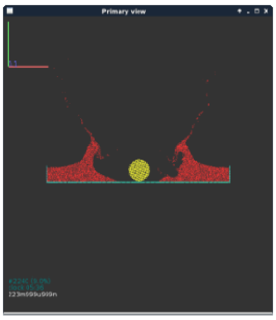
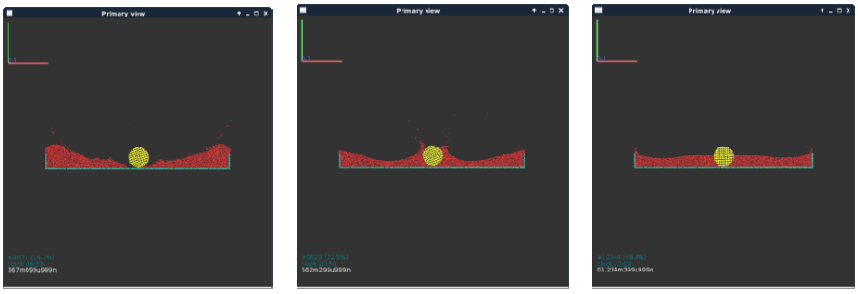


Figure 2: Velocity & Force Variation of One of the Falling Body with Time

Simulation Snapshots

(1) **(2)** **(3)**



(4) **(5)** **(6)**

Figure 3: Simulation Visuals

Results & Interpretations

Hence, YADE simulations were compared to existing literature and experimentations and qualitatively, the results of the simulation were satisfactory. Although a numeric quantitative comparison is yet to be made, still the simulative results which have been obtained are excellent. The disturbance caused to the water film by the grain has been depicted.

SIMULATION OF LIQUID IMPACT ON A LIQUID FILM WHEN DENSITIES OF LIQUID AND LIQUID FILM ARE SAME

Here, an effort has been made to simulate the phenomenon of fall of a liquid droplet on a liquid film, when the thickness of the film is comparable to the diameter of the liquid drop. Here, both the film and droplet have been modelled as water.

Parameters

SPH-Parameters

- density, rho =1000.0 Kg/m3
- viscosity, mu = 1centipoise
- numerical speed of sound squared, k = 1000
- 2D mass correction (ortho packaging:2.855), gamma = 2.855
- gravity acceleration, g = -9.81 m/s2
- time step, O.dt =0.0001s

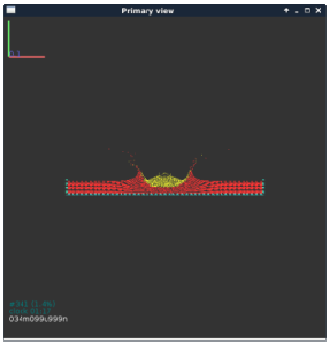
Geometry Parameters

- geometry width, X =.99; geometry height, Y =.066
- number of spheres in z-direction, sphereNumDepth = 1
- number of spheres in y-direction, sphereNumHeight = 19.2
- number of wall layers, sphereNumWall = 2
- sphere radius,Rad = 0.5*Y/sphereNumHeight
- number of spheres in x-direction, sphereNumWidth = 0.5*X/Rad

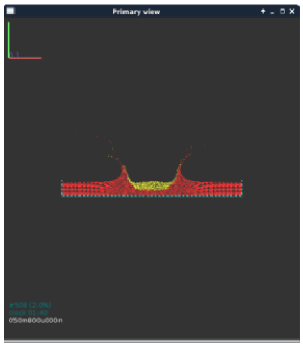
- fallingHeight=0.5*sphereNumHeight/Y
- fallingHeight=discDiam/0.11*0.5/Rad
- number of particles above fluid surface, overHeight = 0.15*sphereNumHeight
- smoothing length, h = 4*Rad

Simulation Snapshots

(1)



(2)



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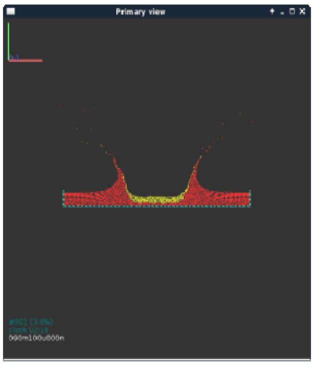
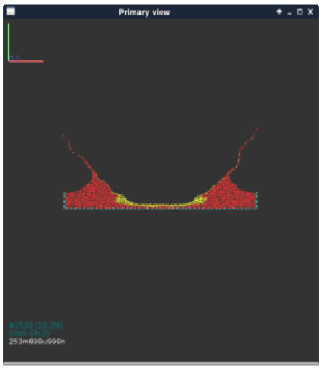
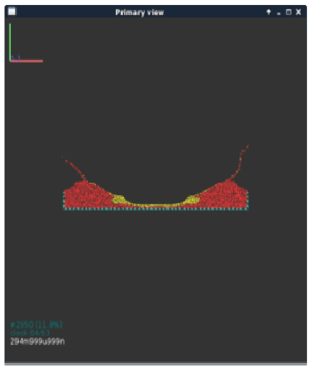


(4)



(5)



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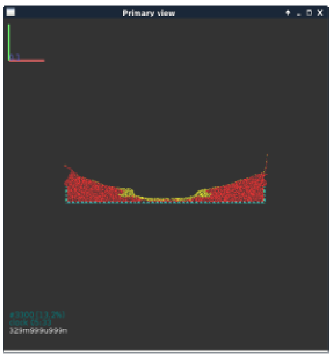

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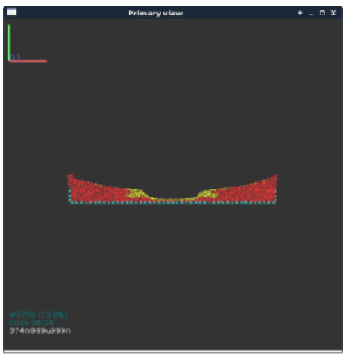

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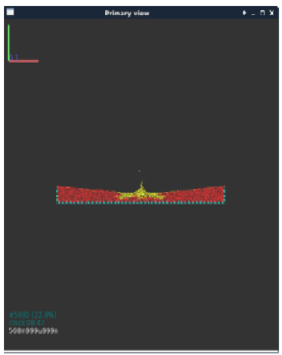

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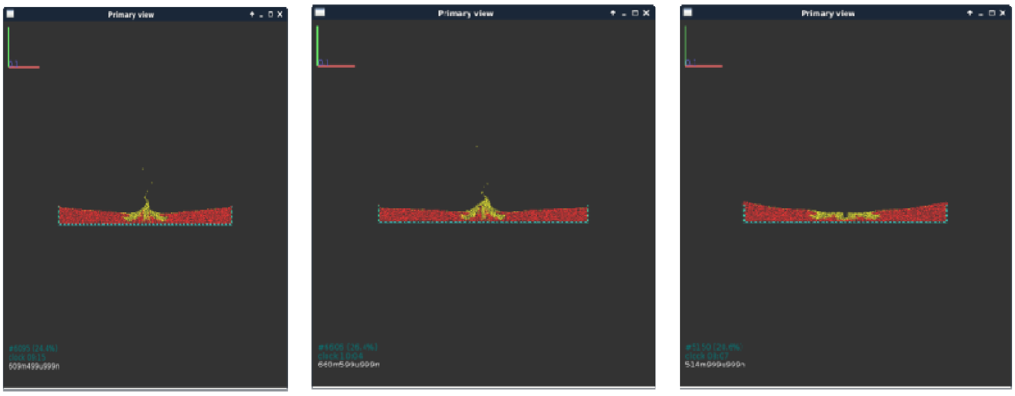

(10) (11) (12)

Figure 4: Simulation Visuals

Results & Interpretations

Hence, YADE simulations were compared to existing literature and experimentations and qualitatively, the results of the simulation were satisfactory. Although a numeric quantitative comparison is yet to be made. Best results have been obtained. Progressively, after falling of the droplet, various stills of the droplet interaction with the liquid film have been captured and the splash, the mixing and the subsiding phases have been shown.

CONCLUSIONS

Hence, using basic SPH techniques discussed before in here, simulations of particle and droplet impact on a liquid water film have been carried out. The idea is to make a benchmark platform for continuous flow testing at industrial level which will remove the necessity of conducting any actual experimentation, which may consume a lot of labor and capital. It is to be noticed at this point of time that the simulation results presented here have been refined to the maximum extent possible. There is always a need to conduct the experiments first manually on a research level, obtaining the parameters at first and then using them for simulation purposes. Once actual data is available, there is always a scope of further implementation and reverse engineering to improve result predictions. Once the algorithms are well set and the simulation results comply well with the actual experimental results, a complete SPH package can then be extensively used to predict flow simulations without conducting experiments at all.

FUTURE SCOPE

The field of continuous flow is vast and still emerging. There is a lot of research still to be done until we can have a complete glimpse of the topic. In this emerging trend of knowledge of granular flows, simulation of such basic flows using YADE as an effective platform can be very helpful to the research scholars to exactly predict the experimental results and to cut down the experimental costs. The given paper has been an effort to dig into a few basics of simulation of continuous flows and to apply certain computational algorithms to simulate a few real-time applications. Still, it is a strong belief of the author that much work has to be done. A few noteworthy points which can be taken up as a future research project have been mentioned below

- Implementation of proper surface tension model in SPH codes
- Conversion of 2-D simulation scripts to 3-D

In fact, a lot more can be done in this field. With the increasing simulation powers and speeds of modern generation computers, there is always a possibility to do whatever you feel like, for the field is relatively new, and hence opportunities increases.

ACKNOWLEDGEMENTS

The above presented work on SPH is a result of extensive training sessions conducted as part of the research and intern training in YADE at TechnischeUniversitatBergakademie Freiberg, Germany. First, the author thanks his adviser and Project Head Prof. Dr.-Ing. habil. RüdigerSchwarze, Institute of Mechanics & Fluid Dynamics, TU Bergakademie Freiberg, Germany for his steadfast guidance throughout his work. He is also graciously indebted to both of his Project mentors, Mr. Anton Gladkyy and Mr. Sebastian Borrmann. The compilation of the results wouldn’t have been possible without the help of program mentors and guides. Author wishes to thank all those who made the project possible from the core of his heart.

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